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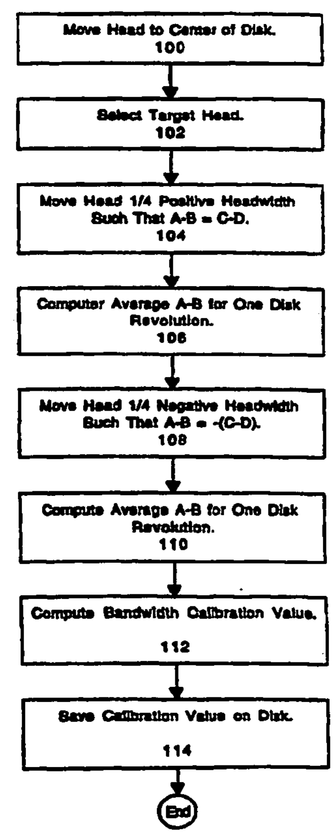
(54) Title: FACTORY CALIBRATION OF SERVO PARAMETERS IN A HARD DISK DRIVE

(57) Abstract

A hard disk drive which has a plurality of calibration parameters stored on the disk of the drive. Calibration values for null current, jam, head width, and bandwidth are stored on the disk surface (114) and accessed during spin-up. The values are precalculated in the factory while testing the disk (100, 102, 104, 106, 108) and then computing a calibration value (112).



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FACTORY CALIBRATION OF SERVO PARAMETERS IN A HARD DISK DRIVE

BACKGROUND OF THE INVENTION

1. FIELD OF INVENTION

The present invention relates to storing calibration parameters on the disk of a hard disk drive.

2. DESCRIPTION OF RELATED ART

Hard disk drives contain a magnetic disk which rotates relative to a transducer (head). The transducer can store and read information from the magnetic disk by magnetizing and sensing the magnetic field of the disk. The magnetized information is typically stored on a plurality of concentric tracks located across the disk. The transducer is mounted to an actuator arm which has a voice coil motor that can move the transducer to the various tracks of the disk. Moving the transducer from track to track is commonly referred to as a seek routine.

To perform a seek routine, a current is provided to the voice coil motor, which produces a torque on the actuator arm and moves the transducer relative to the disk. A typical current profile for a seek routine may include providing a current of one polarity for a predetermined time interval to accelerate the actuator arm, terminating the current to the voice coil motor so that the arm attains a relatively constant velocity, and then providing a current of opposite polarity to decelerate the transducer.

The electronic circuits of present hard disk drives compute the ideal current required to move the transducer from one track to another track. Because of the tolerances associated with mass producing hard disk drives, an ideal current provided to the voice coil motor of one disk drive

may provide different results than the application of the same ideal current within another disk drive. To correct for this deficiency, each individual disk drive must be calibrated to compensate for deviations in the drive unit.

There are presently disk drives that compute a numerical constant, sometimes referred to as the jam value, which is used to create the correct voice coil motor current needed to move the transducer to a desired position. A bandwidth scalar is also computed to compensate for the different magnet strengths of the voice coil motor. Both the bandwidth scalar and the jam value are used by the controller of the disk drive to calculate a seek current for the voice coil.

Once the transducer has reached the desired track, it is desirable to maintain the head in the center of the track to accurately read or write data. To accurately maintain the position of the head on the center of the track it is desirable to determine the actual head width of the transducer. The transducer head width may vary between heads. It is therefore desirable to compute a head width scalar that will compensate for the varying head widths of each transducer.

The rotating disk of a hard drive creates a flow of air that exerts a force on the head of the drive. The force of the air will have a tendency to push the head off track. Additionally, many hard disk drives contain a flexible cable that couples the rotary actuator arm to the electronics of the drive. The flexible cable is typically assembled such that the cable creates a spring force on the actuator arm. To maintain the transducer on the centerline of a track, a null current must be provided to the voice coil motor to create a torque that counteracts the force of the air and the cable. The null current will vary according to the head position, because the air flow and the spring force of the

flexible cable change as the arm travels across the disk. To accurately maintain the position of the transducer on the disk, it is desirable to provide a null current that is a function of the head position.

To compensate for the tolerances and variations in each disk drive, drive units of the prior art compute the above described scalars and values when the disk drive is booted up by the host system. Calibrating all the different disk drive components increases the boot time of the computer. The additional boot time is particularly detrimental when the drive is part of a portable computer which has power down modes that continually power down and then power up the computer. Every time the computer is powered up, the disk drive must recalculate the various scalars and values required to operate the drive. It would be desirable to provide a calibrated disk drive which does not have to compute calibration parameters each time the drive is booted up.

SUMMARY OF THE INVENTION

The present invention is a method of computing and storing a number of calibration parameters onto the disk of a hard disk drive. In accordance with the method of the present invention, after assembly, each disk drive is placed in a calibration station to compute a variety of different calibration parameters that are used to operate the drive. The calibration parameters are then stored to the disk. When the disk drive is subsequently booted up, the controller of the drive unit retrieves the parameters from the disk.

The parameters include null current equations that are used to generate null currents which maintain the transducer of the drive above the centerline of a disk track, a jam current value which is used to accurately move the transducer from one track to another track, a head width calibration value which compensates for the different head widths of each transducer, and a bandwidth calibration value which compensates for the different driving functions of the voice coil motor such as the strength of the motor magnet.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of the present invention will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, wherein:

Figure 1 is a top sectional view of a disk drive;

Figures 2a-b are a flowchart showing the computation of a null current;

Figure 3 is a graph showing the null current versus the location of the transducer relative to the disk;

Figure 4 is a curve which shows a current provided to the voice coil motor of the disk drive;

Figure 5 is a curve which shows the velocity of the head in response to the current of Fig. 4;

Figure 6 is a curve which shows the displacement of the head across the disk;

Figures 7a-c are is a flowchart showing the computation of a jam current value;

Figure 8 is a schematic showing the servo bits of a disk track;

Figure 9 is a flowchart showing the computation of a transducer scalar;

Figure 10 is a flowchart showing the computation of a voice coil motor scalar;

Figure 11 is a graph of the driving function for computing the voice coil motor scalar.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings more particularly by reference numbers, Figure 1 shows a hard disk drive 10. The disk drive 10 has a disk 12 which is rotated by a spin motor 14. The disk 12 spins relative to a head 16 that is mounted to an actuator arm 18. The head 16 contains a transducer which can magnetize and sense the magnetic field of the disk 12. The actuator arm 18 is rotated by a voice coil motor (VCM) 20, which moves the head 16 to one of a plurality of tracks located on the disk 12. The head 16 is coupled to a printed circuit board 22 which contains electronic circuits 24 that control the operation of the drive. The circuits may include a microprocessor based controller, a read only memory (ROM) device and driver circuits for the spin motor 14 and the voice coil motor 20. The voice coil motor drivers provide current to the voice coil 20, which creates a torque on the arm 18 and moves the head 16 relative to the disk 12. After each individual disk drive 10 is assembled, the drive unit is place in a calibration station to compute a number of different calibration parameters. The calibration parameters are typically computed with algorithms stored in the ROM. The controller utilizes the algorithms to compute the various parameters. Although algorithms which are stored on the ROM and used by the disk controller are described, it is to be understood that the calibration station may store the algorithms and compute the values.

After computation, the parameters are then stored onto the disk 12. When the disk drive 10 is incorporated into a host system (not shown), the host will boot up the drive. During the boot up cycle, the controller retrieves the calibration parameters from the disk 12 and uses the parameters to operate the drive unit. The calibration

parameters include null current equations used to generate null currents that maintain the head on the centerline of the track, a jam current value which is used to move the transducer from one track to another stack, a voice coil scalar which compensates for the characteristics of each voice coil motor, a transducer scalar which compensates for the varying head width of each transducer. Although the four listed parameters are described, it is to be understood that other scalars and values can be computed and stored on the disk. Additionally, although the values are described as being computed and stored on the disk, it is to be understood that the values may be initially stored in a RAM device before storage onto the disk.

Figure 2 shows a flowchart showing the steps for computing a pair of line equations that are used to generate null currents for the disk drive. It has been found that different null currents are required to maintain the position of the transducer depending upon the direction of arm movement. There is a line equation for when the arm moves from the inner diameter of the disk to the outer diameter of the disk, and another line equation for when transducer moves from the outer diameter of the disk to the inner diameter of the disk.

As shown in Figure 3, the line equations are determined by moving the transducer to various locations on the disk and measuring the voice coil current required to maintain the head on the center of the disk. Referring to Fig. 2, the transducer 16 is moved to the outer diameter of the disk (point A in Fig. 3) in processing block 30. The head 16 is then moved to a new location B toward the inner diameter of the disk by an increment defined by the outer disk diameter (mincyl) minus the inner disk diameter (maccyl) divided by 5, in block 32. The disk is allowed to rotate a number of

revolutions, while the servo of the drive centers the transducer onto the center of the track. In processing block 34, the null current for maintaining the transducer on the center of the track is saved.

The steps of moving the transducer and saving the null current is repeated at four additional disk locations C, D, E and F shown in block 36. In block 38, the controller computes the slope m and y-intercept of the curve defined by the points B-F by means of a straight line curve fit. The slope m and y-intercept are then stored in block 40.

To compute the second line equation, the transducer is moved to a disk location G located approximately 2/3(maxcyl-mincyl) of the disk from the outer disk diameter (mincyl), in block 42. The transducer is then moved to location H approximately at the mid-point of the disk in processing block 44. The transducer is centered on the track and the 15 null current for point H is saved in block 46. In block 48, the transducer is moved to a disk location I that is approximately 1/3 (maxcyl-mincyl) of the disk from the inner diameter of the disk. In block 50, the transducer is moved from point I to disk location J approximately at the mid-point of the disk. The transducer is centered on the track and the null current for disk location J is saved in block 52.

The null current of the arm movement from the inner disk diameter to the outer disk diameter is defined as the null current from the line equation determined in blocks 30-40, plus the difference in the null currents at disk location H and disk location J $\left(I_{out}=(mx+b)+\left(I_h-I_j\right)\right)$. The difference between the null currents at H and J define the separation between the two curves. From the separation value ΔI_{h-j} the y intercept of the $in \rightarrow out$ curve can be computed. As an

alternate embodiment, the slope (m) of the $in \rightarrow out$ curve can be computed in accordance with processing blocks 30-40.

In processing block 54, the slope m and y-intercepts for both curves ($_{in \rightarrow out}$ and $_{out \rightarrow in}$) are stored on the disk. When the disk drive is booted up, the controller retrieves these values to compute a null current that will maintain the head on the center of a track. The null current for a particular track location when the arm is moving toward the outer diameter of the disk is computed from the equation $I_{in \rightarrow out} = mx + y_{in \rightarrow out}$, where x is the particular track location of the arm. If the arm is moving toward the inner diameter of the disk, the null current is computed from the equation $I_{out \rightarrow in} = mx + y_{out \rightarrow in}$. The null currents are typically used as initial values for centering the transducer, the servo of the disk drive is then used to more accurately center the head.

Figures 4-6 show typical current, velocity and displacement curves, respectively, for a head 16 that is moved from one track to another track. To move the head 16, a current of one polarity is provided to the voice coil 20 for a predetermined time interval. The current creates a torque that accelerates the transducer 16 across the disk. The current to the voice coil 20 is then terminated so that the head 16 attains a relatively constant velocity. After a predetermined time interval, a current of an opposite polarity is applied to the voice coil 20 to decelerate the 20 transducer 16, so that the head 16 is located at the desired disk location. As shown in Fig. 6, variations in the components of the drive unit may cause the head 16 to overshoot or undershoot the desired track location.

Figure 7 shows a flowchart used to calculate a jam current value which will more Accurately move the head to a new track position. In processing block 70, an initial jam current is provided to the voice coil motor. In block 72,

the voice coil motor moves the head to 16 different disk locations and computes a position error for each position. A first average position error is then computed for all 16 positions. The jam current is increased a predetermined increment in block 74. The transducer is then moved to 16 different disk locations and a second average position error is then computed in block 76. In decision block 78, it is determined whether the second position error is less than the first position error.

If the second position error is less than the first position error, the processing path proceeds to block 80 were the jam current is increased an incremental amount. In block 82 the head is moved to 16 different disk locations and a third average position error is computed. In decision block 84 it is determined if the third average position error is less than the second average position error. If the third average error is less than the second error then the steps of incrementing the jam value, moving the head and computing an average position error are repeated until the third error is no longer less then the previous average error value. If the third error is not less than the second error, the jam value is decreased an increment in block 86. The jam value is then stored on the disk in block 88.

If the second average position error is not less than the first average error, the process continues from decision block 78 to block 90 where the jam current is decreased a predetermined increment. The head is moved, an average error value is computed and the new error value is compared to the second average position error in blocks 92 and 94. If the new error is greater than the second error, then the jam value is incremented in block 96 and stored on the disk in block 98. When the disk drive i8 booted up, the controller retrieves the stored jam current value from the disk 12 and

uses the jam value to generate a jam current that moves the head from one track to another track.

Figure 8 shows a number of servo bits or burst that are written onto a track of the disk 12. It is preferable to read and write all data on the center of the track. It is therefore desirable to maintain the head on the center of the track. The head position is maintained by the controller and accompanying circuitry by a servo routine that reads and interprets servo bits stored on the disk. The servo bits A, B, C and D shown in Fig. 8 are used by the servo routine of the drive to maintain the head on the center of the track. Servo bit A is located at a position approximately 1/2 a negative track width from the center of the track. Servo bit B is located at approximately 1/2 a positive track width from the center of the track. Servo bit C is located on the center of the track and servo bit D is located a full positive track width from the center of the track.

When locating the position of the head it is desirable to calculate the actual offset displacement of the transducer relative to the center of the track. Because of variations in the head fabrication process, each head has a different effective head width. Figure 9 shows a flowchart used to calculate a transducer scalar which compensates for different head widths of each head. In processing block 100, the heads 16 are moved to the center of the disk. One of the heads is selected in block 102. In block 104, the head is moved to a location 1/4 of ~ positive track width from the center of the track. The 1/4 track location defined as the track location where the signals of servo bits A-B = C-D. An average of A-B signals is then computed for a single revolution of the disk in block 106.

In block 108, the head is moved to a location 1/4 of a negative track width from the center of the disk. The 1/4

negative track location is defined as the track location where servo bit signals A-B = -(C-D). An average of A-B for a complete revolution of the disk is computed in block 110. In block 112 a headwidth calibration value for the target head is then computed by dividing a gain constant by the difference in the average A-B value for the positive 1/4 head track position from the A-B value for the negative 1/4 head track position $Cal = constant / \left((A-B)_{ave+1/4}\right) - \left((A-B)_{ave-1/4}\right)$. The calibration value is then stored on the disk in block 114.

The process of computing a headwidth calibration value 5 is computed for each head in the disk drive. When the disk drive is booted up, the controller retrieves the calibration values and uses the values to determine the actual offset position of the heads by multiplying the headwidth scalars with the offtrack voltages measured by the heads.

Figure 10 shows a flowchart used to calculate a voice coil motor scalar which compensates for varying voice coil motor characteristics in each drive unit. For example, the magnets of each drive unit might have a different strength that will create a different torque for a given current. The 15 Scalar is used to vary the current provided to the voice coil to compensate for the different voice coil motor magnet strength, so that a given current will create a predictable torque.

In block 120, the head is moved to the mid-point of the disk. A driving function is applied to the voice coil to move the head off of the center of the track a predetermined distance (OffsetComm) in block 122. A position error signal (PES) corresponding to the actual movement of the head is determined in block 124. In block 126, the ratio of a position error (PERR), defined as OffsetComm minus the position error signal PES, is divided by the position signal error PES (OffsetComm-PES)/PES. In block 128, a bandwidth

calibration value is computed by multiplying the ratio PERR/PES by a constant K. The constant is typically the unity 1, so that the calibration value is equal to the ratio PERR/PES. The calibration value is then stored on the disk 12 in block 130. The bandwidth calibration value is retrieved by the controller when the disk drive is booted up. The scalar is used to vary the current to the voice coil to compensate for the variations in the voice coil motor characteristics.

In the preferred embodiment, the driving function for the head is a sinusoidal wave shown in Figure 11. The frequency of the sine wave is preferably established so that the ratio of PES/PERR is 1, which correlates to 0 on a log-log graph. The ideal cross-over frequency (PES/PERR=1) is preferably provided as the driving function. The PES/PERR ratio computed in block 126 is the amount of deviation from unity at the ideal cross-over frequency.

What is provided are methods for computing various calibration parameters that are then stored on the disk of the drive unit. Storing the parameters on the disk 15 significantly reduces the boot up time of the disk drive.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

What is claimed is:

1. A hard disk drive, comprising:

a disk which contains a calibration parameter, said disk being defined by a plurality of tracks;

a spin motor that rotates said disk; a transducer coupled to said disk;

an actuator arm attached to said transducer; and,

a voice coil motor coupled to said actuator arm.

2. The hard disk drive as recited in claim 1, further comprising a controller that retrieves said calibration parameter from said disk when said spin motor initially rotates said disk.

3. The hard disk drive as recited in claim 1, wherein said calibration parameter is a null current value which is used to create a null current that is provided to said voice coil motor to maintain said transducer on a track.

4. The hard disk drive as recited in claim 1, wherein said calibration parameter is a jam value which is used to generate a seek current that is provided to said voice coil motor to move said transducer from one track to another track.

5. The hard disk drive as recited in claim 1, wherein said calibration parameter is a head width calibration value which is used to determine an offset position of said transducer.

6. The hard disk drive as recited in claim 1, wherein said calibration parameter is a bandwidth calibration value which is used to calibrate said voice coil motor.

7. A method for storing calibration parameters of a disk drive, comprising the steps of:

a) spinning up a hard disk drive;

b) computing a calibration parameter; and,

c) storing said calibration parameter on a disk of said hard disk drive.

8. The method as recited in claim 7, further comprising the steps of;

d) spinning down said hard disk drive;

e) spinning up said hard disk drive; and,

f) reading said calibration parameter from said disk.

9. A hard disk drive, comprising:

a disk which contains a null current value, said disk being defined by a plurality of tracks; a spin motor that rotates said disk;

a transducer coupled to said disk; an actuator arm attached to said transducer;

a voice coil motor coupled to said actuator arm; and,

servo circuit means for retrieving said null current value and generating a null current that maintains said transducer adjacent to a track.

10. The hard disk drive as recited in claim 9, wherein said null current value is computed from a line equation derived by moving said transducer to a first track and saving first null current value, and moving said transducer to a second track and saving a second null current value.

11. The hard disk drive as recited in claim 10, wherein said null current value is computed from an inner-to-outer line equation derived when said transducer moves from an inner diameter of said disk to an outer diameter of said disk, and an outer-to-inner line equation derived when said transducer moves from said outer diameter of said disk to said inner diameter of said disk.

12. A method for generating a line equation for a null current value that is used to generate a null current which maintains a transducer on a track of a disk, comprising the steps of:

a) moving a transducer to a first track;

b) measuring a first current value required to maintain said transducer on said first track;

c) moving said transducer to a second track;

d) measuring a second current value required to maintain said transducer on said second track;

e) computing a line equation from said first and second current values; and,

f) storing said line equation on a disk.

13. The method as recited in claim 12, further comprising the steps of repeating steps (c) and (d) a predetermined number of times, wherein said transducer is moving from an inner diameter of said disk to an outer diameter of said disk and an inner-to-outer line equation is computed with said current values.

14. The method as recited in claim 13, further comprising the steps of moving said transducer from said inner diameter of said disk to a third track located toward

said inner diameter of said disk and measuring a third current value, moving said transducer toward said inner diameter of said disk to a fourth track, moving said transducer from said fourth track to said third track and measuring a fourth current value, and computing an outer-to inner line equation that is a function of said inner-to-outer line equation and the difference between said third current value and said fourth current value.

15. A hard disk drive, comprising:

a disk which contains a jam value, said disk being defined by a plurality of tracks;

a spin motor that rotates said disk;

a transducer coupled to said disk;

an actuator arm attached to said transducer;

a voice coil motor coupled to said actuator arm; and,

seek circuit means for retrieving said jam value and generating a seek current that moves said transducer from one track to another track.

16. A method for creating a jam value that is used to generate a seek current which moves a transducer across a disk, comprising the steps of:

a) moving a transducer to a predetermined disk track by providing a first current to a voice coil motor;

b) computing a first position error;

c) increasing said first current an incremental amount 8 to move said transducer to a track;

d) computing a second position error;

e) increasing said first current an incremental amount to move said transducer to a new track if said second position error is less than said first position error, or decreasing said first current an incremental amount to move

said transducer to said new track if said second position error is greater than said first position error;

f) computing a third position error;

g) repeating steps (e) and f) until said third position error is at least equal to said second position error; and,

h) storing a jam value on a disk, wherein said jam value corresponds to a jam current provided in step (e) such that said third position error is at least approximately equal to said second position error.

17. The method as recited in claim 16, wherein each track movement is repeated a predetermined number of times and an average position error is computed.

18. A hard disk drive, comprising:

a disk which contains a head width calibration value, said disk being defined by a plurality of a spin motor that rotates said disk;

a transducer coupled to said disk;

an actuator arm attached to said transducer;

a voice coil motor coupled to said actuator arm; and,

servo circuit means for retrieving said head width calibration value to determine an actual displacement between said transducer and a center of a track.

19. A method for generating a head width calibration value that is used to determine a transducer location relative to a track of a disk, comprising the steps of:

a) providing a plurality of servo bits on a disk track which has a centerline, said servo bits including a first bit located a positive one-quarter track from the track centerline and a second bit located a negative one-quarter track from the track centerline;

b) moving a transducer a positive one-quarter track from the track centerline;

c) measuring a first positive one-quarter bit voltage associated with said first bit and a first negative one-quarter bit voltage associated with said second bit;

d) moving a transducer a negative one-quarter track from the track centerline;

e) measuring a second positive on-quarter bit voltage associated with said first bit and a second negative one-quarter bit voltage associated with said second bit;

f) computing a head width calibration value as a function of a difference between said first positive and negative one-quarter bit voltages and a difference between said second positive and negative one-quarter bit voltages; and,

g) storing said head width calibration value on a disk.

20. A hard disk drive, comprising:

a disk which contains a bandwidth calibration value, said disk being defined by a plurality of tracks;

a spin motor that rotates said disk;

a transducer coupled to said disk; an actuator arm attached to said transducer;

a voice coil motor coupled to said actuator arm; and,

voice coil motor circuit means for retrieving said bandwidth calibration value to calibrate a current that is provided to said voice coil motor.

21. A method for generating a bandwidth calibration value to calibrate a current that is provided to a voice coil motor which moves a transducer relative to a disk, comprising the steps of:

a) providing a current to a voice coil motor to move a transducer an offset position relative to a track centerline of a disk;

b) measuring a position error signal that correlates to an actual transducer position relative to the track centerline;

c) computing a bandwidth calibration value as a function of said offset position and said position error signal; and,

d) storing said bandwidth calibration value on said disk.

22. The method as recited in claim 21, wherein said transducer is moved in accordance with a sinusoidal driving function.

23. The method as recited in claim 21, wherein said bandwidth calibration value is a computed from a ratio of, a position error defined as a difference between said offset position and said position error signal, and said position error signal.

FIG. 1

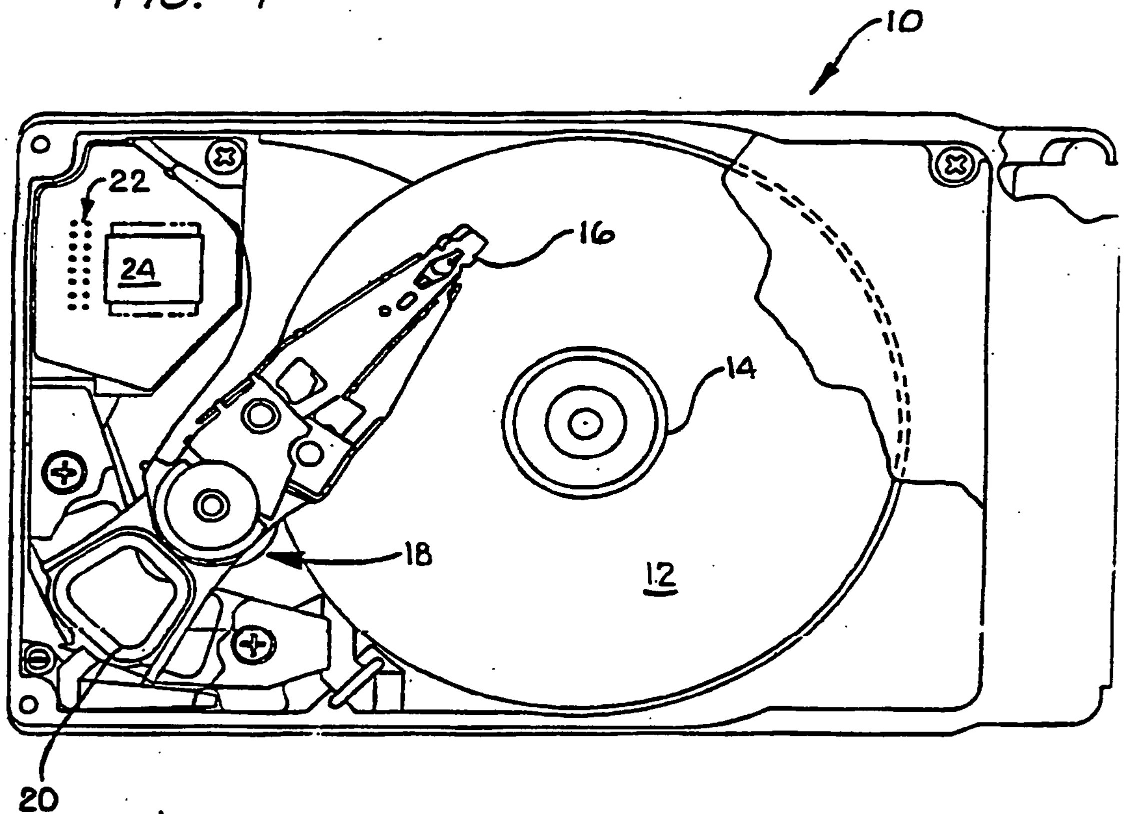
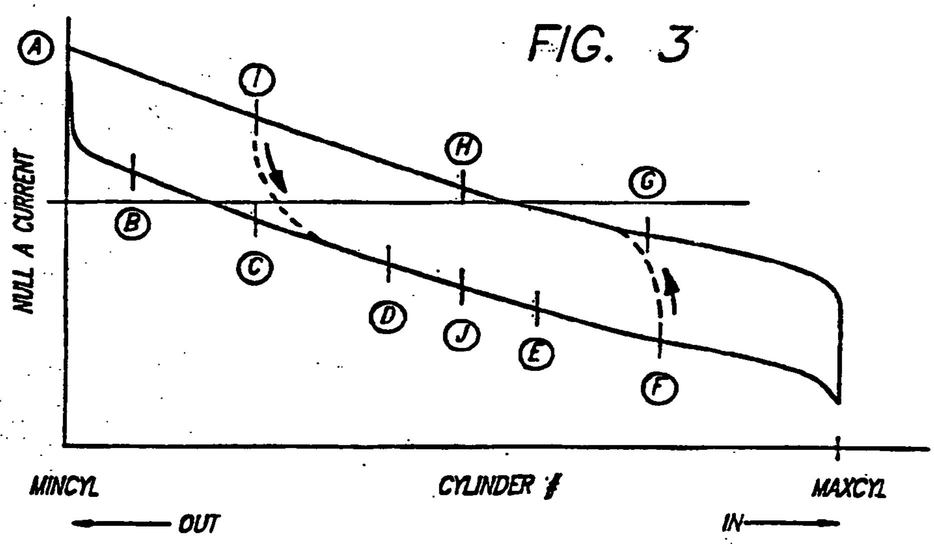

10
22
24
16
14
18
12
20

FIG. 3


A
I
H
G
B
C
D
J
E
F
NULL A CURRENT
MINCYL
CYLINDER #
MAXCYL
OUT
IN

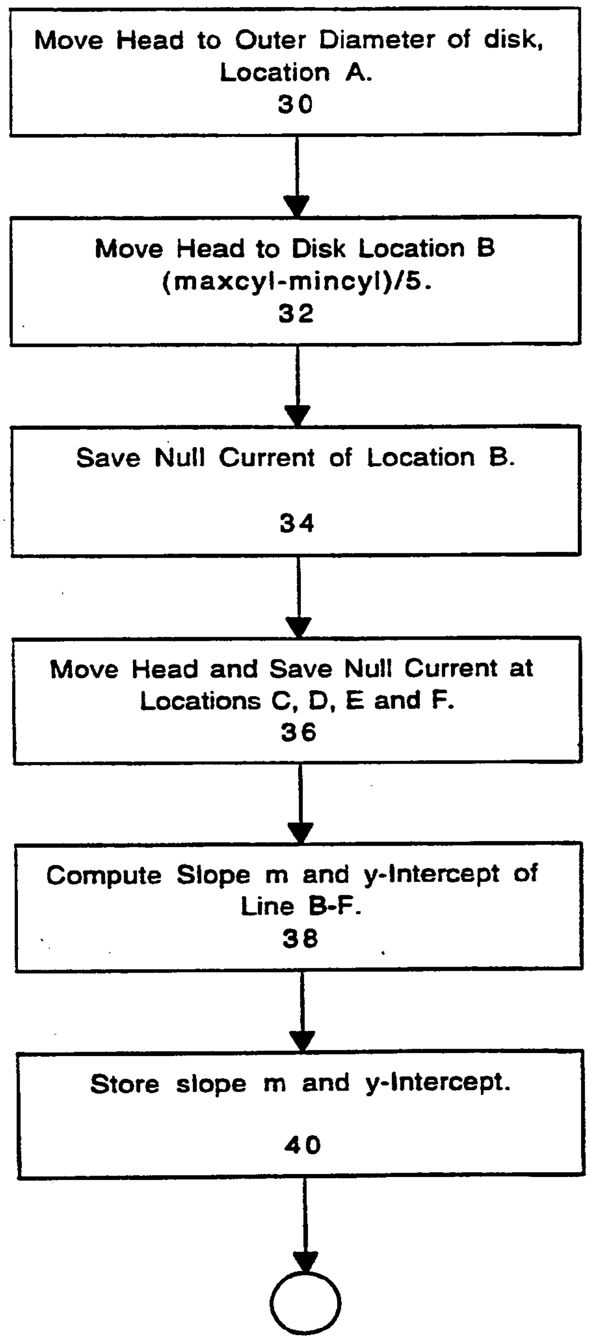

Move Head to Outer Diameter of disk, Location A.
30
Move Head to Disk Location B (maxcyl-mincyl)/5.
32
Save Null Current of Location B.
34
Move Head and Save Null Current at Locations C, D, E and F.
36
Compute Slope m and y-Intercept of Line B-F.
38
Store slope m and y-Intercept.
40

FIGURE 2a

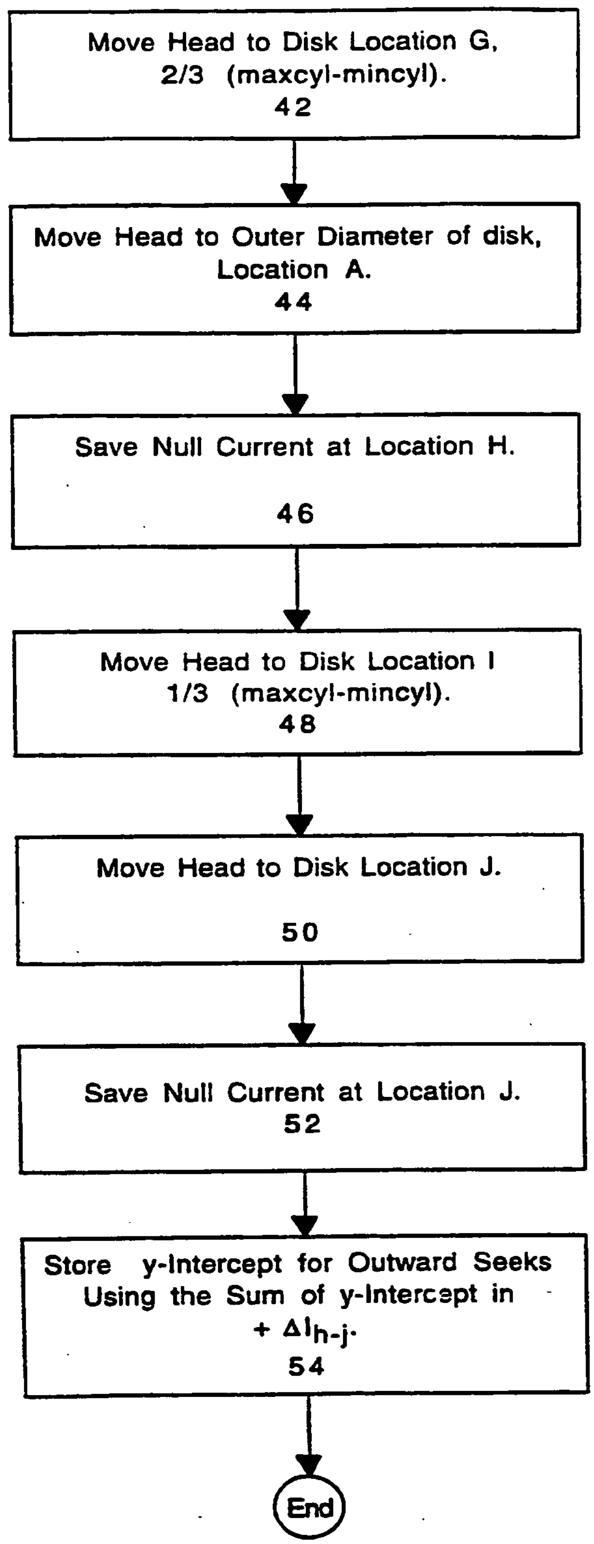

Move Head to Disk Location G,
2/3 (maxcyl-mincyl).
42
Move Head to Outer Diameter of disk,
Location A.
44
Save Null Current at Location H.
46
Move Head to Disk Location I
1/3 (maxcyl-mincyl).
48
Move Head to Disk Location J.
50
Save Null Current at Location J.
52
Store y-Intercept for Outward Seeks
Using the Sum of y-Intercept in
+ ΔI_{h-j}.
54
End

FIGURE 2b

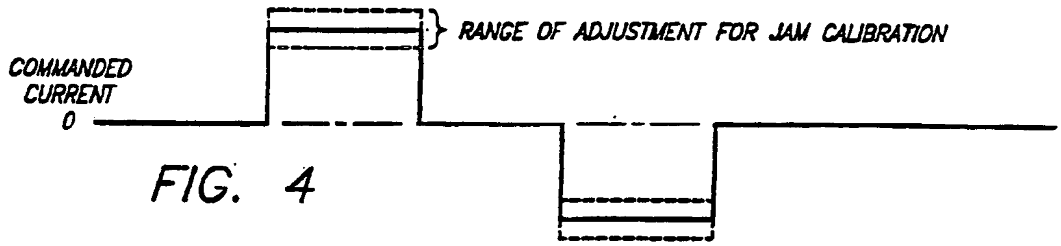


FIG. 4

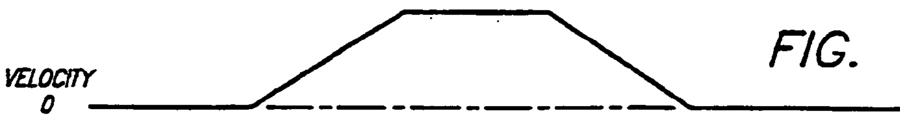


FIG. 5

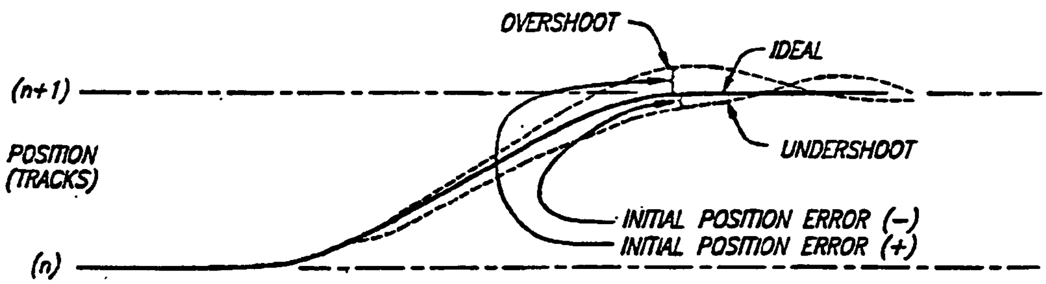


FIG. 6

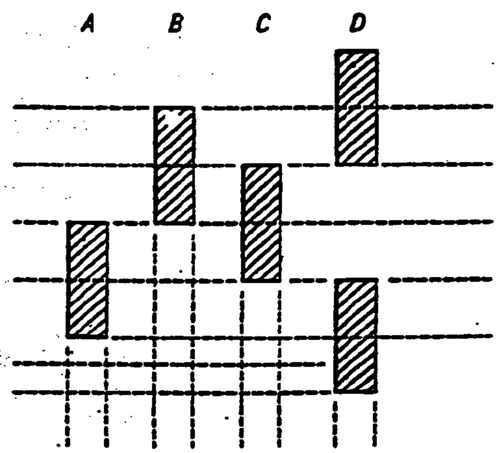


FIG. 8

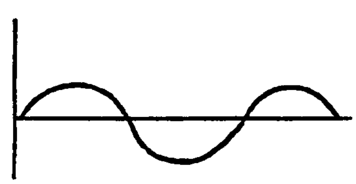


FIG. 11

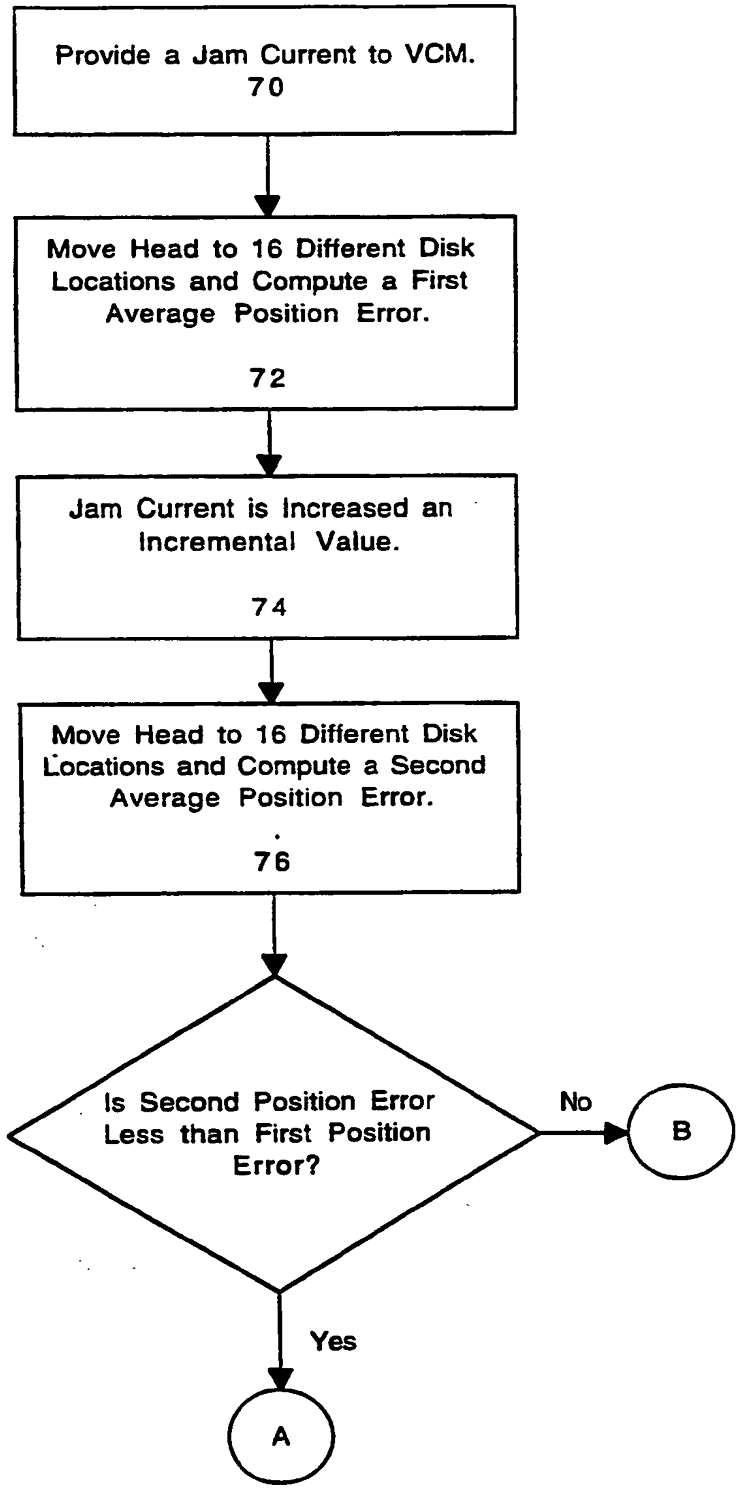

Provide a Jam Current to VCM.
70
Move Head to 16 Different Disk Locations and Compute a First Average Position Error.
72
Jam Current is Increased an Incremental Value.
74
Move Head to 16 Different Disk Locations and Compute a Second Average Position Error.
76
Is Second Position Error Less than First Position Error?
No
B
Yes
A

FIGURE 7a

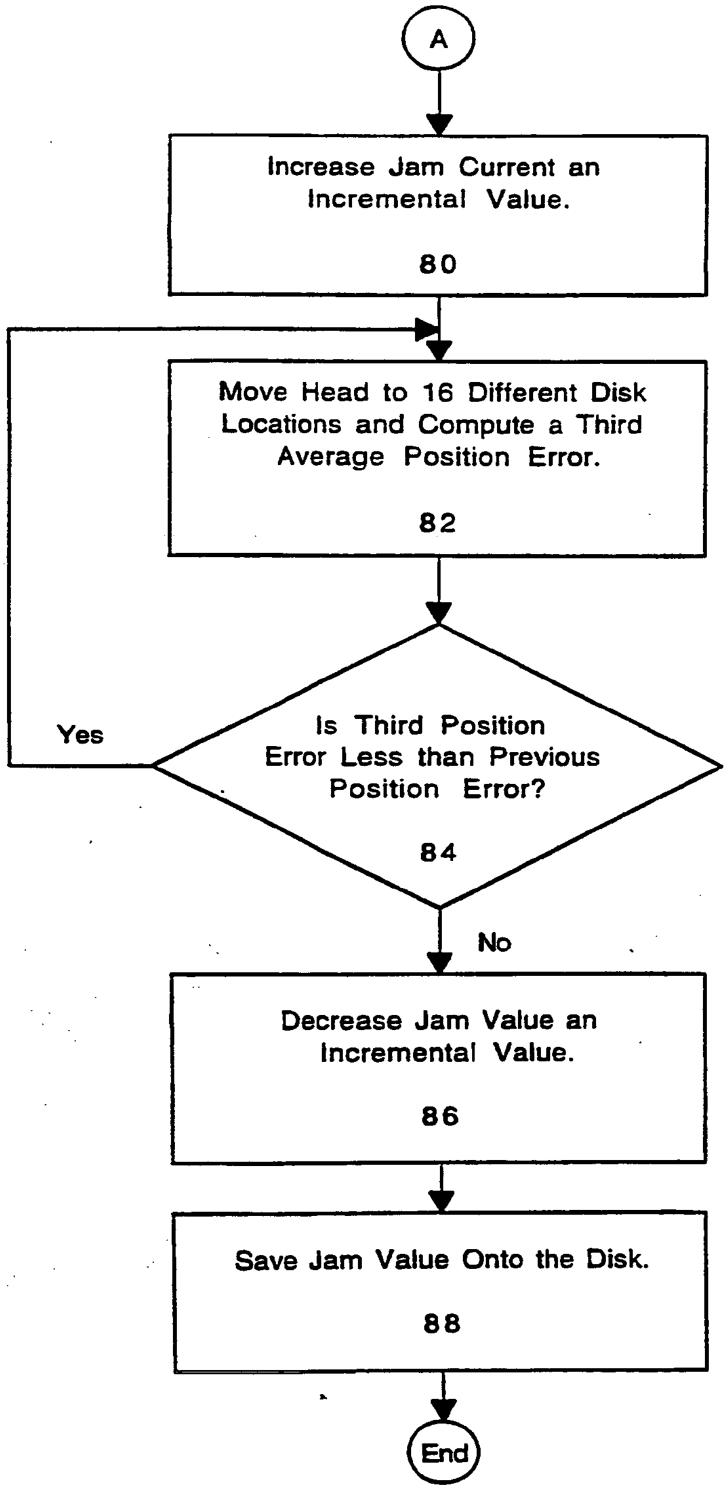

A
Increase Jam Current an Incremental Value.
80
Move Head to 16 Different Disk Locations and Compute a Third Average Position Error.
82
Yes
Is Third Position Error Less than Previous Position Error?
84
No
Decrease Jam Value an Incremental Value.
86
Save Jam Value Onto the Disk.
88
End

FIGURE 7b

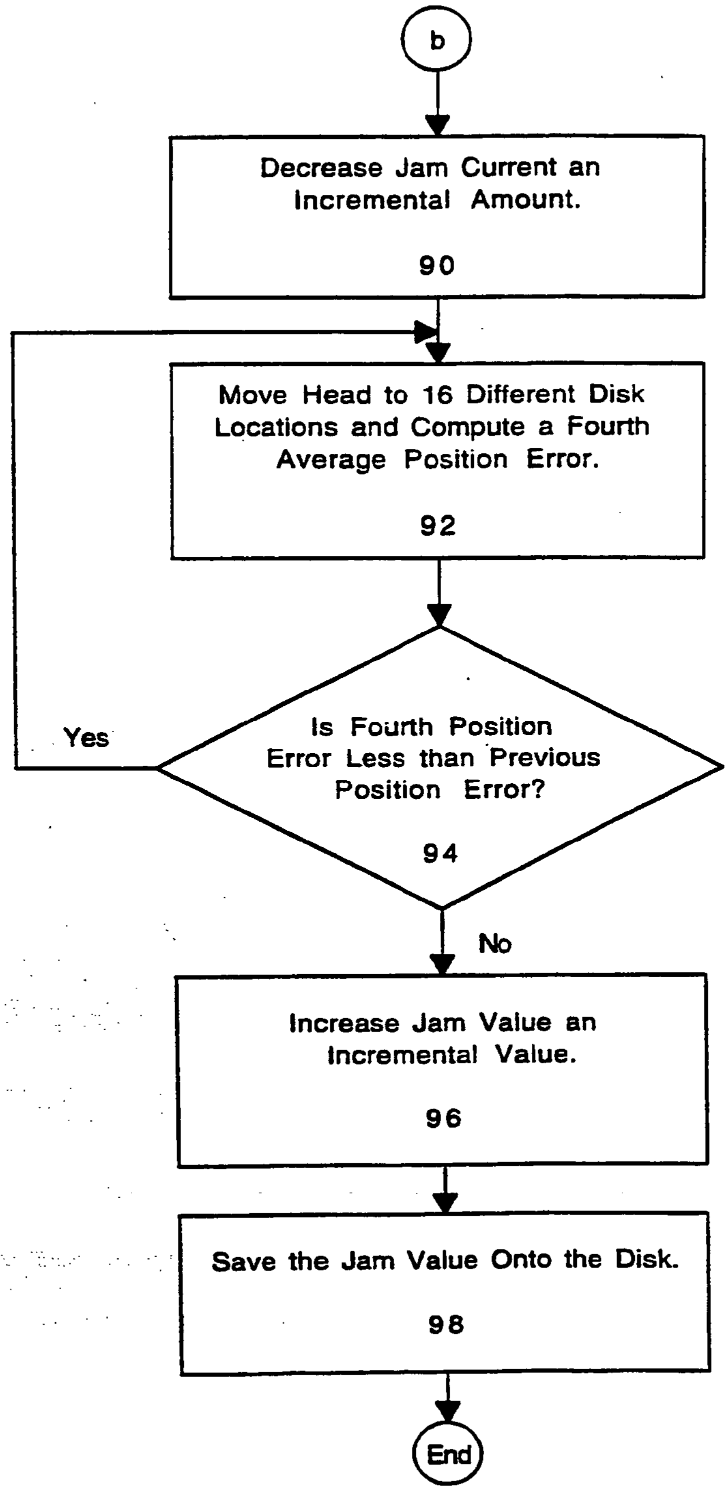

b
Decrease Jam Current an Incremental Amount.
90
Move Head to 16 Different Disk Locations and Compute a Fourth Average Position Error.
92
Is Fourth Position Error Less than Previous Position Error?
94
Yes
No
Increase Jam Value an Incremental Value.
96
Save the Jam Value Onto the Disk.
98
End

FIGURE 7c

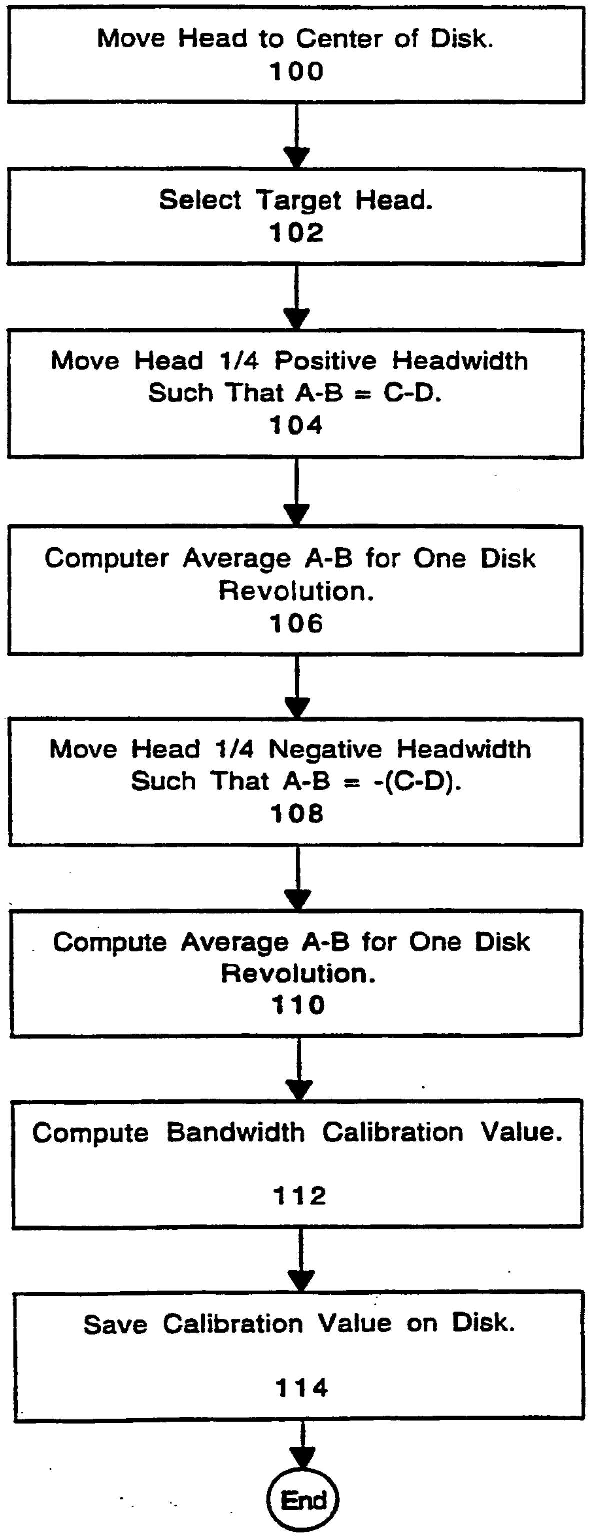

Move Head to Center of Disk.
100
Select Target Head.
102
Move Head 1/4 Positive Headwidth Such That A-B = C-D.
104
Computer Average A-B for One Disk Revolution.
106
Move Head 1/4 Negative Headwidth Such That A-B = -(C-D).
108
Compute Average A-B for One Disk Revolution.
110
Compute Bandwidth Calibration Value.
112
Save Calibration Value on Disk.
114
End

FIGURE 9

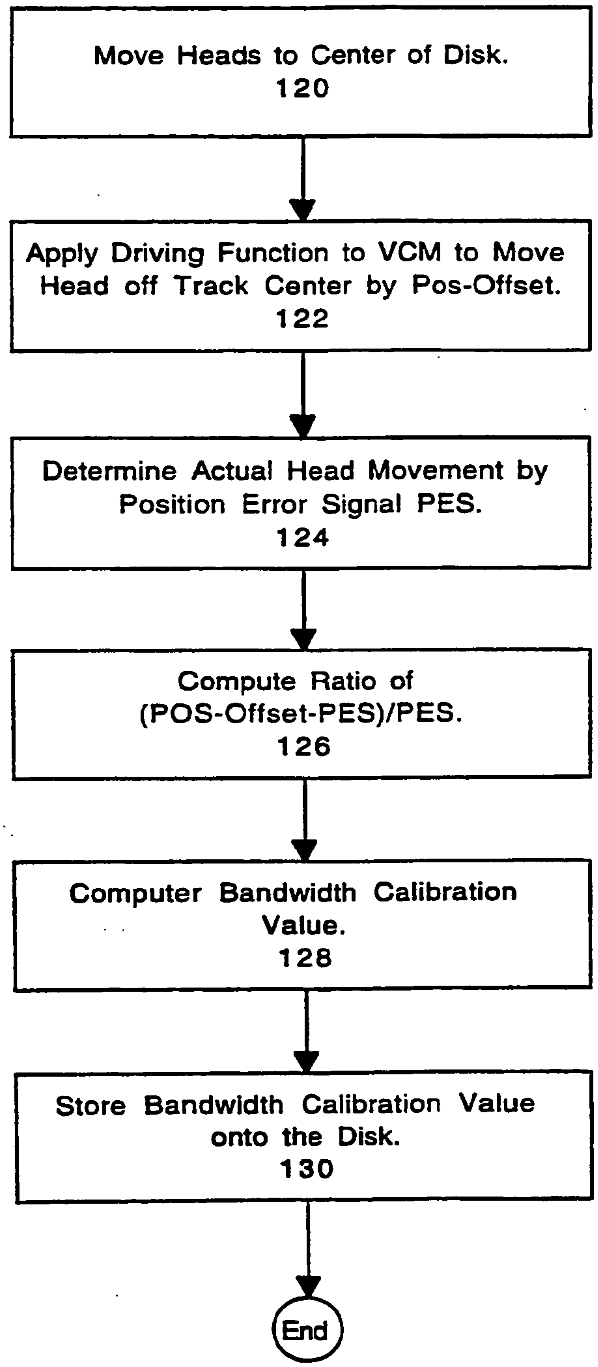

Move Heads to Center of Disk.
120
Apply Driving Function to VCM to Move Head off Track Center by Pos-Offset.
122
Determine Actual Head Movement by Position Error Signal PES.
124
Compute Ratio of (POS-Offset-PES)/PES.
126
Computer Bandwidth Calibration Value.
128
Store Bandwidth Calibration Value onto the Disk.
130
End

FIGURE 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/07257

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G11B 5/596, 27/36
US CL : 360/78.04, 31, 78.09, 75
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 360/78.04, 31, 78.09, 75

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, JPOABS
calibration, disk, start, initialize, null current

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,121,260 (Asakawa et al.) 09 June 1992, col. 3, lines 30-42	1-2, 7-8 ----------- 3, 9-14
Y	US, A, 5,005,089 (Thanos et al.) 02 Apr 1991, col. 24, lines 43-55	3, 9-14
Y	US, A, 4,783,705 (Moon et al.) 08 Nov 1988, col. 27, lines 15-53	3, 9-14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 SEPTEMBER 1995	04 OCT 1995

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/07257

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-3 and 7-14

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains claims directed to more than one species of the generic invention. These species are deemed to lack Unity of Invention because they are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for more than one species to be examined, the appropriate additional examination fees must be paid. The species are as follows:
A disk drive using calibration parameters with the disk having (a) null current calibration values, as described on pages 8-10 and as shown in Figure 2, (b) jam calibration values, as described on pages 10-13 and as shown in Figure 7, (c) head width calibration values, as described on pages 12-13 and as shown in Figure 9, and (d) bandwidth calibration values, as described on page 13-14 and as shown in Figure 10.
The claims are deemed to correspond to the species listed above in the following manner: Species (a) - claims 3 and 9-14; Species (b) - claims 4 and 15-17; Species (c) - claims 5, 18, and 19; Species (d) - claims 6 and 20-23. The following claims are generic: 1, 2, 7, and 8.
The species listed above do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, the species lack the same or corresponding special technical features for the following reasons:
The limitations provided by the generic claims are old and well known in the art and thus they do not provide special technical features. Each of the above species has individual characteristics which are distinct from each other species.